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A novel orthogonally activated double-Hall device

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Abstract

The offset and its temperature drift are almost fully compensated in a novel design orthogonally activated silicon double-Hall device. The proposed sensor consist two functionally integrated three-contact Hall elements sharing the same transducer region with rectangular shape and common central electrode. Two pairs equal in value but opposites in direction supply currents are formed by the structure symmetry and using equal resistors. In an orthogonal magnetic field, the Lorentz force deviate the pairs of current paths in opposite directions. The Hall elements have almost equal offsets, the offset temperature drifts are perfectly matched and Hall voltages are equal in value but of opposite sign. The output signal is given by subtraction of two output voltages using a circuitry with three op-amps. The residual offset was about 140 times lower than the individual ones in the range – 10 ºC ≤ T ≤ 80 ºC and the magnetic-field depended signal is almost doubled.

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Keywords: double Hall device; offset compensation; Hall elements

1. Introduction

The offset and its temperature drift are major drawbacks, seriously impeding the accuracy of Hall sensors in dc magnetometry. No universal approach for their compensation acceptable for metrological purposes is currently available. The most common methods used in Hall elements, such as improvement of the manufacturing processes and device symmetry, perfection of the static and dynamic cancellation techniques, including current spinning approach etc., are not sufficiently justified by the achieved results. One of the most acceptable solutions of these problems is to use orthogonal double-Hall elements [1,2] consisting two single Hall devices sharing the same active

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region. The complicated design (8 contacts) of these sensors quite often renders them inadequate for high-resolution measurements. This paper suggests a novel orthogonal double-Hall device with almost fully compensated offset within a wide temperature range.

2. The offset compensated Hall devices setup

2.1. Device design and principle of operation

The proposed novel *n*-Si orthogonal double-Hall sensor is shown in Fig. 1.

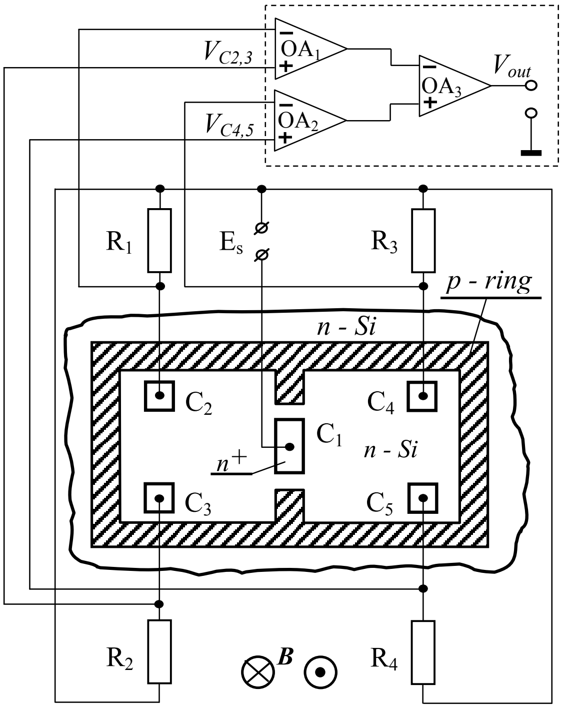


Fig. 1. Plan-view of the double-Hall sensor with the novel coupling circuitry.

The microdevice is designed by part of the fabrication steps generally used in a bipolar integrated process with four masks. The distance $l_{C1,2}=l_{C1,3}=l_{C1,4}=l_{C1,5}$ and $l_{C2,3}=l_{C4,5}$ are 30 µm and 20 µm respectively; the *n*-Si low-doped substrate resistivity is $\rho \approx 7.5$ Ω.cm. The width of the rectangular *p*-well ring is about 30 µm. The planar contacts C_2 , C_3 , C_4 and C_5 are connected via four load resistors of equal value $R_1=R_2=R_3=R_4 >> R_{int}$, where R_{int} is the internal device resistance. The middle contact C_1 is fed to the power-supply, Fig. 1. This way, four equal in value supply components, $|I_{C1,2}|=|I_{C1,3}|=|I_{C1,4}|=|I_{C1,5}|$, are formed by the symmetry and resistors $R_1=R_2=R_3=R_4$. In the absence of magnetic field, initially the current paths $I_{C1,2}, I_{C1,3}$, $I_{C1,4}$ and $I_{C1,5}$ under equipotential highly doped n^+ contacts C_1, C_2, C_3, C_4, and C_5 are vertical, further they are parallel to the upper surface. In the presence of magnetic field $\boldsymbol{B} > 0$, perpendicular to the substrate plane, the Lorentz force acting on lateral current components appeared: $\boldsymbol{F}_L = q.\boldsymbol{V}_{dr} \times \boldsymbol{B}$, q being electron charge. The action of the $\boldsymbol{F}_L$ on the lateral components of drift velocity $\boldsymbol{V}_{dr}$ depends on the directions of $\boldsymbol{B}$, and currents $I_{C1,2}, I_{C2,3}$, $I_{C4,5}$ and $I_{C5,6}$. Due to the Lorentz force**,** the currents $I_{C1,2}, I_{C2,3}$, $I_{C4,5}$ and $I_{C5,6}$ deflect towards p – ring in different ways as they have different directions. Therefore, according to the directions of the currents and the field $\boldsymbol{B}$*,* $I_{C1,2}$ and $I_{C1,5}$ increase/decrease, while components $I_{C1,3}$ and $I_{C1,4}$ decrease/increase respectively by the same value. Through the resistors, the change of the currents in a magnetic field $\boldsymbol{B}$ is transformed into Hall voltages. As a result two sensor signals – V_{sens1} and V_{sens2} may be extracted. Each of them includes a Hall voltage and offset voltage: $V_{sens1} = V_{C2,3}(0) + V_{C2,3}(\boldsymbol{B})$, $V_{sens2} = V_{C4,5}(0) + V_{C4,5}(\boldsymbol{B})$. These two Hall voltages have equal value but opposite sign, $V_{C2,3}(\boldsymbol{B}) = -V_{C4,5}(\boldsymbol{B})$, like [1]. Since the two single Hall devices act on the same region, the offset temperature drifts are perfectly matched and the offsets are almost equal, $V_{C2,3}(0) \approx V_{C4,5}(0)$. Therefore, if subtract these two sensor signals, the offsets and their drift will be dramatically reduced and the Hall signal will be doubled: $V_{C2,3}(0) + V_{C2,3}(\boldsymbol{B}) - [V_{C4,5}(0) + V_{C4,5}(\boldsymbol{B})] = 2V_H(\boldsymbol{B}) + [V_{C2,3}(0) - V_{C4,5}(0)]$, where $|V_H(\boldsymbol{B})| = |V_{C2,3}(\boldsymbol{B})| = |V_{C4,5}(\boldsymbol{B})|$

2.2. Electronic interface circuitry and sensor signal processing

The novel coupling is achieved by hybrid realization, using precise quad matched resistor network and instrumentation amplifiers as discrete electronic components. The resistors $R_1=R_2=R_3=R_4$ are implemented as precise quad matched resistor network LT5400. These resistor networks is proper for such application, because they provide excellent matching (up to 0.025%), 0.2ppm/°C matching temperature drift, 8ppm/°C absolute resistor value temperature drift, long-term stability: <2ppm at 2000 Hrs. As is shown above, the Hall voltage must be doubled and the residual offset should be reduced drastically, if both output sensor signals V_{sens1} and V_{sens2} are subtracted from each other. To do this, both differential sensor outputs are connected to the differential-input amplifiers A_1 and A_2 of the dual-channel AD8222B. To maintain minimum gain error and gain drift, for both A1 and A_2, we choose identical gains G = 1 with no external gain resistor. In such case, the gain error is 0.02% only. The output voltage of A_1 is $V_{out,A1}= G_1V_{sens1} = G_1(V_{C2,3}(0) + V_{C2,3}(\boldsymbol{B}))$ and the output voltage of A_2 is $V_{out,A2}= G_2V_{sens2} = G_2(V_{C4,5}(0) + V_{C4,5}(\boldsymbol{B}))$, where $G_1=G_2=1$. For subtracting operation, the instrumentation amplifier A3 is used. For this purpose, we choose the precise instrumentation amplifier AD8422BRZ. The output voltage $V_{out,A3}$ of A_3 is the device output V_{out}: $V_{out,A3}= V_{out} = G_3(V_{sens1} - V_{sens2})=G_3(V_{C2,3}(0) + V_{C2,3}(\boldsymbol{B}) - V_{C4,5}(0) - V_{C4,5}(\boldsymbol{B}))$. As $V_{C2,3}(\boldsymbol{B}) \sim - V_{C4,5}(\boldsymbol{B})$ and $V_{C2,3}(0) \sim V_{C4,5}(0)$, we may write down

$$V_{out} = G_3(2V_H \pm V_{res}) \qquad (1)$$

where $V_{res} = V_{out}(0)$ is so-called residual voltage, which is considerably less than $V_{C2,3}(0)$ and $V_{C4,5}(0)$.

3. Experimental results

The dependencies $V_H(\boldsymbol{B})$ are shown in Fig. 2. The offsets are compensated in advance. The channel sensitivity is S_R = 63 V/AT, as the device sensitivity reaches 122 V/AT at amplification gain G = 1. The temperature dependence of the offset voltage $V_{C2,3}(0,T)$, as well as the residual offset $V_{out}(0,T)$ after subtraction are shown in Fig. 3(a). The offset $V_{out}(0)$ is about 140 times less than the individual ones. The measured power spectral density of the internal noise for channel $V_{C2,3}(0)$ is shown in Fig. 3(b). The supply current I_{C1} is as a parameter, T = 20 °C. The $V_{C4,5}(0)$ noise channel behavior is the same. Since the new sensor uses directly current deflection on relatively small-sized ohmic contacts instead of surface charges' accumulation, the surface random phenomena decreased and hence the noise drops. The lowest detected induction B_{min} is about 6 μT in the range 1 Hz – 100 Hz. The internal $1/f$ noise is also reduced about 10 times, Fig. 4.

4. Conclusions

The presented novel orthogonal double-Hall device reveals a new possibility for almost fully offset compensation within a wide temperature range. The conditioning circuitry is simple, containing three op-amps as the conversion of differential current changes into Hall voltages is achieved by one precise quad matched resistor network only. The obtained experimental results are very promising for robotics "vision", low-field magnetometry, speed and direction sensing devices, ABS systems etc.

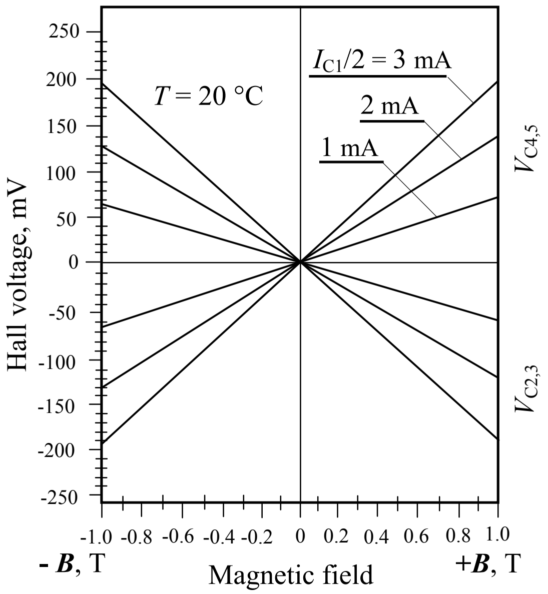
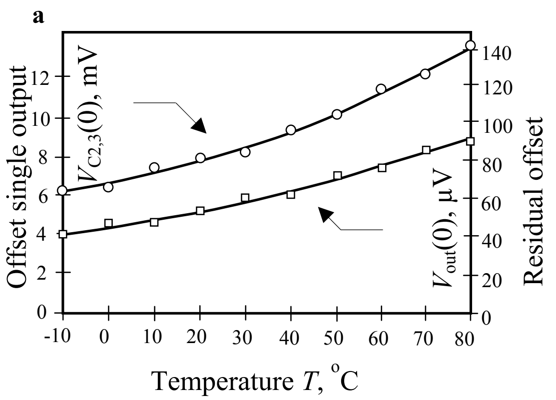


Fig. 2. The magnetic response of outputs.



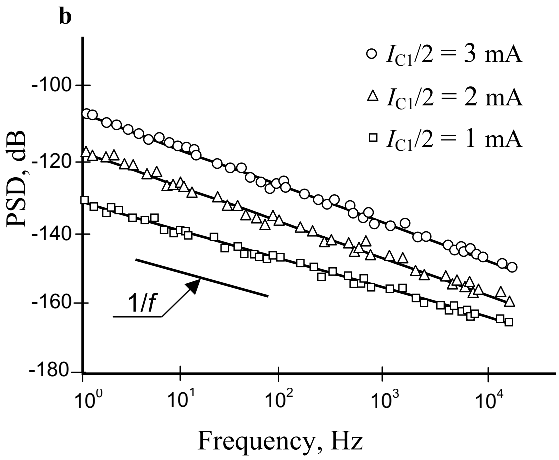


Fig. 3. (a) Thermal behavior of $V_{C2,3}(0)$ and $V_{out}(0)$; (b) The measured power spectral density of noise for channel $V_{C2,3}(0)$.

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